Spiral galaxies with non-typical mass-to-light ratios.

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Abstract

Total mass-to-light ratio M/L_B for $S0-Irr$ galaxies, where M is the dynamical mass within the optical radius R_{25}, increases systematically with $(B-V)_0$ color, but slower than that is predicted by stellar population evolution models. It shows that the mean ratio between dark halo and stellar masses is higher for more "blue" galaxies. However some galaxies don't follow this general trend. The properties of galaxies with extremely high and extremely low values of M/L_B ratios are compared, and different factors, accounting for the extremes, are analyzed. The conclusion is that in some cases too high or too low M/L_B ratios are associated with observational errors, in other cases - with non-typical dark halo mass fraction, or with peculiarities of disc stellar population. Particularly, discs of some galaxies with low M/L_B ratios turn out to be unusually "light" for their luminosity and colors, which indicates a substantial deficit of low mass stars as the most probable cause of low M/L_B.

1 Introduction.

Total mass-to-light ratio M/L, just as mass-to-light ratio M_*/L for a stellar disc is an important parameter that reflects both dark matter (dark halo) contribution to the total mass of a galaxy and the properties of the disc stellar population (the age distribution of stars, stellar initial mass function IMF, and to a lesser degree - the stellar population metallicity). Direct measurements show that in most cases the total mass-to-light ratios does not fall outside the limits in the range of 1-10 in the B, V, R bands (here and below the solar units of $M_\odot/L_\odot$ are used) and are close to unit in near infrared bands. Hence, M/L ratios which differ significantly from their typical values may indicate either peculiar stellar population, or extremely low (high) relative mass of dark matter (dark halo), or may be the result of errors of luminosity and/or mass estimations.

Luminosity of stellar population L is estimated more reliably than total mass of a galaxy. The main systematic error of luminosity estimation comes from the uncertainty of corrections for the internal dust extinction, which is significant for highly inclined galaxies. Photometric parameters, reduced to face-on orientation of galaxies by applying the statistically determined corrections, are available in different catalogs and databases (see, for example, NASA Extragalactic Database, [1], HyperLeda, [2]).

The situation with the measurement of total mass of galaxies appears to be more complicated. The direct mass measurements can be done only on the basis of stellar or gas dynamics, but even in this case the results depend strongly on the assumed model of a galaxy, especially if we are interested to find the masses of its main components: the disc, the bulge and the dark halo. As far as the concept of a total mass of a galaxy is uncertain enough, the mass estimations are often related to some fixed radius. It's convenient to use the radius R_{25}, corresponding to the isophote $25^m/sq.arcsec$ in the B band, as the boundary

one. This radius contains nearly total luminosity of a disc, unless low surface brightness (LSB) galaxies are considered.

The halo mass is often comparable to mass of a stellar disc within the optical radius of a galaxy, although the question of universality of the ratio of these masses for galaxies of a given type remains opened. In general, the higher is the dark mass fraction and the lower is the fraction of young massive stars, the higher is the M/L ratio for the galaxy. To separate these two factors the additional information is needed, such as a color of the disc or shape of rotation curve. Therefore it's of interest to compare the galaxies with extremely high and low total M/L ratios to reveal the most probable reason of their extreme M/L values.

2 Total M/L ratios of disc galaxies.

To determine the influence of the dark halo and stellar population on the total M/L ratio, the optimum way is comparison of dynamical and photometric estimations of masses. Both methods are model dependent. Photometric method of stellar mass measurement is based on stellar population evolution models, which predict a strong correlation between broad-band colors and M_*/L ratios of stellar component. This correlation slightly depends on both star formation history and the effect of selective absorption, (see for example Bell, de Jong, [3], Portinari, [4]). Theoretical evaluations of M_*/L_B or M_*/L_V, obtained for models with slowly varying (for example exponential declining in time) star formation rate (SFR) and for usually accepted IMFs, lead to values of about one solar unit for the bluest galaxies with active star formation and 5-10 for "red" galaxies consisting of old stars.

In practice, in some cases the mass values, obtained by photometric and dynamical methods give strongly different results, although for high luminous galaxies with accurate rotation curves the results are usually in a reasonable agreement (see Salucci al., [5], Kassin et al., [6], de Blok et al., [7]). Nevertheless, the obtained correlation between colors and M_*/L ratios, where M_* is found from the rotation curve modeling, is not so tight as it is theoretically expected (see, for example, the diagrams, presented by Bell, de Jong, [3], Graham, [8], Giraud et al., [9], McGaugh, [10], Barnes et al., [11], Yoshino, Ichikawa, [12]). One may suppose, that a loose correlation is associated not only with a low accuracy of mass determination, but also with a bad choice of parameters of photometric models, such as a stellar IMF, to the real galaxies.

The estimation of the total dynamical mass of a galaxy is more reliable, than that for the disc. The mass within R_{25} can be obtained with the reasonable accuracy from the equation:

$$M = K \cdot V^2 R_{25}/G \tag{1}$$

where $K \approx 1$ is a coefficient, which depends on mass distribution within the galaxy, and V is a circular velocity at R_{25}. As the first approximation it may be assumed, that $K = 1$ and $V = W_{HI}/2\sin i$, where W_{HI} is HI line width, and i is the disc inclination. The M/L_B ratios found by this way usually lay in the range between several solar units up to 10 - 20 units. High M/L_B ratios ($M/L_B > 10$) are very rare and occur mostly in dwarfs or in LSB-galaxies. Indeed, there are only two galaxies with $M/L_B > 10$ (UGC 3303 ($M/L_B = 31$) and NGC 5128 ($M/L_B = 17$)) among the nearly a hundred galaxies brighter than $M_B = -16^m$ (in other words, that are not extremely low luminous dwarfs), which are given in Karachentsev catalog of nearby galaxies [13]. Note that for one of these galaxies, peculiar galaxy NGC 5128 (type $S0$), a more accurate model gives lower value of M/L_B, namely: 3.9 for a central part of the galaxy and about 10 within R = 25 kpc (Xui et al., [14]). Another examples of non-dwarf galaxies with high M/L_B ratios mentioned in the literature, are Scd-galaxy UGC

7170, M/L_B of which is about 43 within the radius of 100" (that is little bit more than R_{25}) (Cox et al., [15]), and LSB galaxy UGC 128, (Zavala et al., [16]) with $M/L_B = 34$ within 5 disc radial scalelengths (adopted to Hubble constant H_0 =75 km/s/Mpc, assumed in present work). It is worth noting that the discs of all these galaxies are observed edge-on, hence their high M/L_B may be a result of underestimation of light extinction in these cases.

Extremely low mass-to-light ratios ($M/L_B < 1$) are observed mostly in dwarf gas-rich galaxies with active star formation. Really, there is no any object with $M/L_B < 3$ among 79 galaxies of different types, luminosity and surface brightness, considered by Zavala et al., [16], (where dynamic masses were evaluated within five radial scalelengths of a disc, that is little larger, than R_{25}). Extremely low M/L_B are expected to be found in starburst galaxies where young stellar population gives the main contribution to luminosity. In this case such a galaxy should also have a low $(B - V)$ color. The presence of massive dark halo may nevertheless increase its ratio M/L_B.

The connection between the dark halo mass fraction and other properties of galaxies is a matter of discussion. As it is reported by some authors, mass fraction of dark halo tends to be higher in the galaxies with lower luminosity (mass) (Persic, Salucci, [17], Yegorova, Salucci, [18], Pizagno et al., [19], de Blok et al., [7]) or central surface brightness (Zavala et al., [16]). Nevertheless, total M/L_B ratios within optical radius correlate slightly or do not correlate at all neither with luminosity, nor with the mean surface brightness or morphological type, as it is revealed by nearby galaxies (Karachentsev et al., [13]).

Diagram "M/L_B – $(B - V)_0$", where the mass M is determined from the equation (1), and the total corrected colors of galaxies are taken from HyperLeda [2], is shown in Fig.1a. The sample consists of about 1300 S0 - Irr galaxies, selected from HyperLeda, that are brighter than $B = 14^m$, and have the inclination $i > 40^0$ (to minimize the uncertainty in i). Dwarf galaxies with the luminosity $L_B < 3 \cdot 10^8 L_\odot$ are practically absent in the sample.

A wide range of M/L_B values, from 30 to 1/30, extending at about two orders of magnitude, is partially a result of indirect method of determination of rotation velocity V from the hydrogen linewidth which in some cases lead to considerable errors, for example, due to non-circular motions of gas (remember, that $M \sim V^2$). Nevertheless, for most of the galaxies M/L_B lay in the expected range between 1 and 10 solar units. Black line in Fig.1 shows the relation, predicted by the photometric evolution model (Bell, de Jong, [3]) which uses a modified (bottom-light) Salpeter IMF. The top end of the line corresponds to the galaxies, that consist of old stars only, whereas the bottom end - to galaxies with active star formation.

In spite of the wide spread of points on the graph, a bulk of galaxies follows the well defined sequence, running above the model relation at some angle to it. After the exclusion of points beyond 2σ limits (after two iterations), the correlation is described by the following linear regression relation:

$$M/L_B = a_B(B - V)_0 + b_B, \qquad a_B = 1.24, b_B = -0.26. \tag{2}$$

The difference between the observed and model sequences may be understood as a result of the presence of a dark halo in galaxies, which increases M/L_B ratio. Comparison of the slopes of these two lines on the graph enables us to conclude that the ratio of dynamical to stellar masses within R_{25} decreases systematically from $M/M_* \approx 3 - 5$ for galaxies with $(B-V)_0 \approx 0.3-0.5$ to ≤ 1.5 for the reddest galaxies. This conclusion does not change if to use L_V luminosity rather than L_B. For this case the coefficients of the linear regression are: $a_V = 0.06$, $b_V = 0.83$. Note, that the conclusion about the increasing of the ratio between stellar and total masses with $B - R$ color indices was made by Graham, [8] for about a

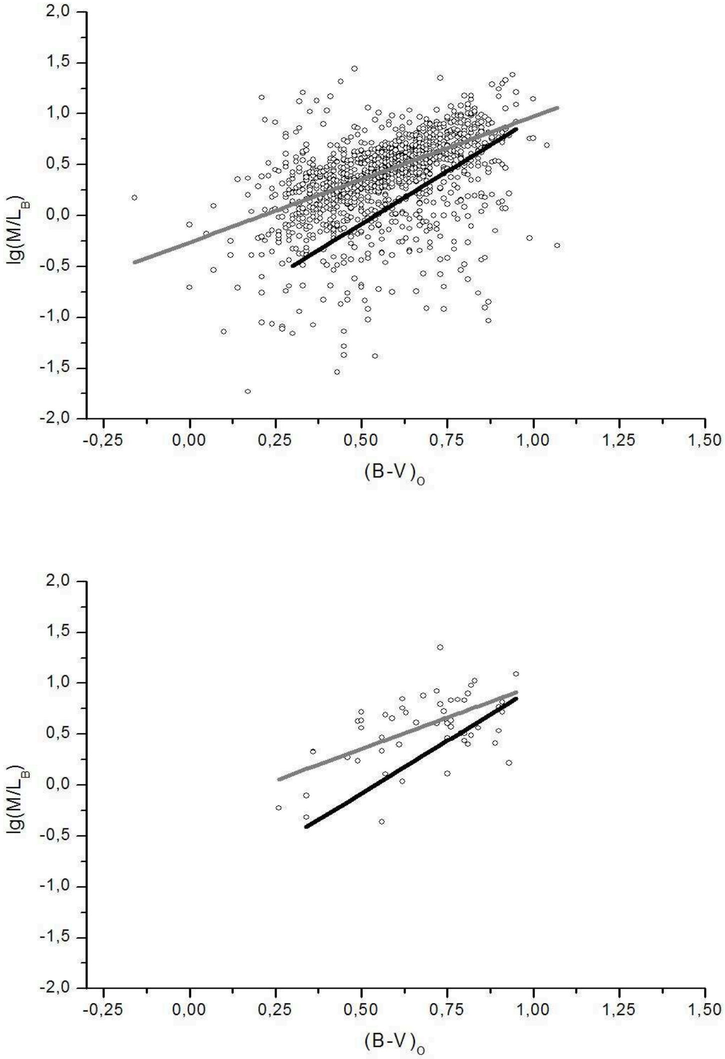

Figure 1: Total M/L_B ratios within the optical radius R_{25} against the total corrected $(B-V)_0$ colors. a) the entire sample, b)Virgo galaxies. Gray line shows the least-squares fit (after 2σ rejection), black line is a model relationship for evolving stellar systems (Bell, de Jong, [3]).

hundred spiral galaxies, however the correlation between M/L_B and $B-V$ color was not found by this author.

A similar relation is plotted in Fig. 1b for nearby massive galaxy cluster Virgo. The comparison between Figs 1a,b shows that Virgo galaxies do not differ much in their locations on the diagram. Despite of different formation conditions, the ratio between the stellar disc and dark halo masses of cluster galaxies seems to correlate similarly with color index. It gives evidence that the relative mass fraction of dark matter within the optical disc is statistically connected with the stellar composition of galaxies, that is with the evolution of their stellar population, rather than with the environment. Dark halo mass contribution appears to be on the average lower for galaxies in which the fraction of young stars is low. The relation between the amount of the dark matter and the star formation history requires a special investigation. It may be supposed, that it is caused by the influence of large-scale gravitational instabilities of stellar-gas disc of a galaxy on star formation. When the dark

halo mass fraction is low, the disc is self-gravitating, that induces the development of the large-scale instabilities and decreases the time of gas consumption. As a result, the present time star formation has the low level of activity.

Note that correlation between the M/L_B ratios and morphological type of galaxies is practically absent. The exception are Irr- galaxies, for which the M/L_B ratios are usually lower, evidently as the result of the active star formation. We also didn't find a statistically significant correlation between M/L_B or M/L_V ratios and HI mass, normalized by luminosity (parameter *hic* in HyperLeda [2]), which one would expect, if the dark matter contribution were connected with the mass fraction of HI, as it was supposed by several authors (see for example, Pfenniger, Revaz, [20]). A correlation coefficient between $lg(M/L_B)$ and *hic* for our sample was found to be as low as 0.2.

It is remarkable that some galaxies have M/L_B ratios, which are considerably lower than those predicted by the model M/L-color correlation for stellar systems. This disagreement is enhanced if to take into account the presence of dark halo in these galaxies. Either the errors of estimations, or the exotic stellar mass function with a deficit of low massive stars is required to explain the observed low M/L_B ratio. This problem will be discussed further in the next Section.

3 A comparison of galaxies with high and low M/L_B ratios

Hereafter we consider in more detail the cases of significant deviations of points on the M/L_B-color diagram from the evolution model correlation. For this purpose we will compare two groups of galaxies: those with $M/L_B < 1$ and with $M/L_B > 10$. We name these two groups as "light" and "heavy" galaxies respectively. In principle, if to seek for the galaxies with extremely low or extremely high mass fraction of dark halo, there is a good possibility to find them in these two groups (those with low dark matter fraction - among the "light" galaxies and those with high dark halo fraction - among the "heavy" ones).

The distributions of "light" and "heavy" galaxies and the entire sample of galaxies (5685 objects) by morphological type and $(B-V)_0$ are compared in Figs. 2a and 2b. As may be inferred from the histograms, both "light" and "heavy" groups consist of galaxies with different morphological types and colors. However, "light" galaxies are on the average bluer, in the comparison with the general sample (the mean values of $(B-V)_0$ differ by 0.1). However, some red objects also may be found among the "light" galaxies.

The color of galaxies with $M/L_B > 10$ in most cases corresponds to old stellar population ($(B-V)_0 > 0.7$). Nevertheless, about one third of these galaxies demonstrates rather low color index ($(B-V)_0 < 0.5$). They appear to have on average lower luminosity, so the conclusion about high mass fraction of dark matter is quite reasonable for them. In general, galaxies with high M/L_B ratio are massive systems of S0–Sbc (T= -2 – +4) types. Situation is different for galaxies with low M/L_B: they have practically the same frequency of occurrence among various morphological types, including early types S0–Sa (T=-2 – +1). About 40% of "light" galaxies have comparatively low dynamical mass $M \leq 10^{10} M_\odot$. On the contrary, the mean mass of "heavy" galaxies is higher than that for the other galaxies, although their mean luminosity is practically the same as for the whole sample.

To reduce the probability of significant errors in M/L_B estimations we choose those galaxies which have the measured rotation curves, because they allow to find the maximum rotation velocity more reliably than from the HI linewidth. Mass M for these galaxies was also derived from the equation (1), where the velocity V was taken from the curve of

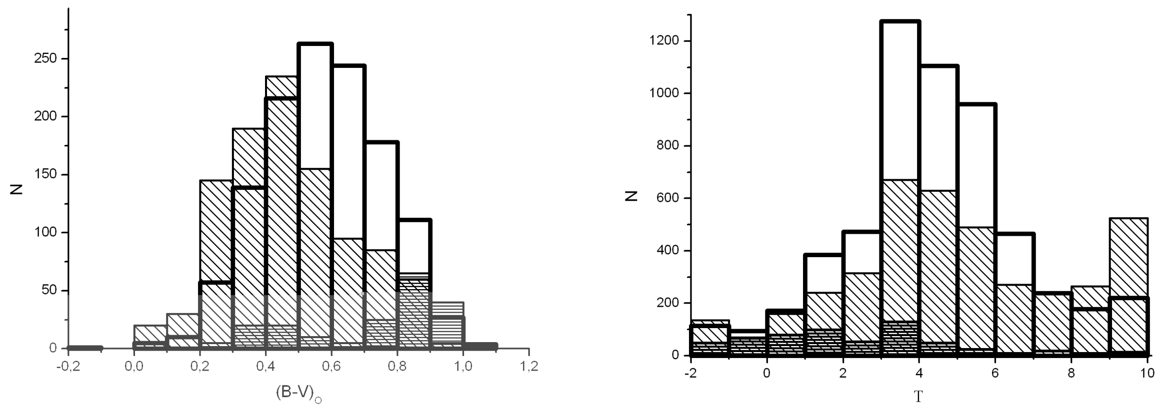

Figure 2: Histograms, showing the distribution of galaxies by $(B-V)_0)$ color (a) and by morphological type (b). The thick line shows the entire sample of galaxies, cross hatch relates to "light" galaxies ($(M/L_B < 1)$, horizontal hatch relates to "heavy" galaxies ($M/L_B > 10$). The number of "light" and "heavy" galaxies is multiplied by the factor of 5 for a comparison convenience.

rotation. The rotation curve sources were mostly found in the Resolved kinematical data catalog from HyperLeda database [2]. If two or more references are found for the rotation curve of the same galaxy, the curve with lower scatter of points was favored. More than 50 galaxies from both samples with published rotation curves were found, most of them for the "light" galaxies.

The comparison of rotation velocities V derived from HI linewidth with those taken from the rotation curve reveals a good agreement, although there are a few objects with a significant discrepancy, exceeding 50 km/s, between these estimations. As the next step, we excluded from further consideration those galaxies, where the new estimates of M/L_B based on the rotation curves allowed to exclude them from the "light" or "heavy" samples. After this procedure the number of all considered galaxies decreased roughly by a quarter (roughly by a third for "heavy" galaxies). Some of properties of these galaxies are listed in Tables 1 and 2. To improve the statistics, the galaxies with $1 \leq M/L_B \leq 2$ were added to the list of the "light" galaxies. Tables 1 and 2 contain:
(1) – Name
(2) – Distance D in Mpc
(3) – Inclination
(4) – Morphological type
(5) – M/L_B ratio
(6) – R_{max}/R_{25} ratio, where R_{max} is the radius, at which the measured rotation curve extends.
(7) – Source of rotation curve
(8) – Method of rotation velocity measurement (o - optics, r - radio)
(9) – Notes (g - galaxy in group, c -in cluster, p - in non-interacting pair, p,i - in interacting pair)

From Tables 1 and 2 it follows, that the "light" and "heavy" galaxies exist among – the relatively isolated systems and group members, which confirms that the environment does not affect strongly the total M/L_B ratio.

With the exception of two actively star forming galaxies with poor quality rotation curves, which possess the lowest values of $M/L_B < 0.15$ (NGC 1569 and ESO 338-004), the minimum

Table 1: “Light” galaxies with known rotation curves.

Galaxy (1)	D, Mpc (2)	$i,^0$ (3)	t (4)	M/L_B (5)	R_{max}/R_{25} (6)	Source (7)	Estimation method (8)	Notes (9)
ESO 008-001	57.3	89	SB(s)d	0.9	0.83	[21]	o	–
ESO 038-012	66.8	68	SAB(rs)bc	1.0	1.25	[21]	o	g
ESO 121-006	13.4	87	Sc	0.5	0.93	[21]	o	–
ESO 338-004	37.7	55	S-?	0.1	0.63	[22]	o	–
ESO 490-028	26	80	Sb	1.0	0.91	[21]	o	p
ESO 565-011	61.1	33	S0-a	1.8	0.95	[23]	o	–
ESO 586-002	88.6	75	S	0.3	1.36	[21]	o	–
NGC 1569	2.2	60	IBm	0.1	1.89	[24]	r	–
NGC 2550	32.1	72.6	Sb	0.7	0.71	[25]	o	–
NGC 3396	21.4	90	Ibm	0.2	0.27	[26]	o	p, i
NGC 3991	43.4	90	IB	0.6	0.95	[27]	o	g
NGC 4668	20.4	67.5	SB(s)d	0.9	0.7	[25]	o	p
NGC 5134	21.8	54.9	SABb	0.5	0.63	[25]	o	p
NGC 4826	7	59	SAab	1.7	2.45	[28]	r	c
NGC 5954	27.2	61	SAB(rs)cd	0.7	1.23	[29]	o	p, i
NGC 6814	20.7	22	SAB(rs)bc	0.3	2.41	[25]	o	–
UGC 03685	26.8	31	SB(rs)b	0.4	4.27	[30]	r	–
ESO 215-039	55.12	48	SABc	0.6	0.95	[21]	o	–
NGC 4618	6.3	35	SBm	1.3	2	[31]	r	p, i
IC 4221	37.33	64.6	SBc	1.7	0.75	[25]	o	–
NGC 1160	35.25	62	SBc	1.9	0.72	[32]	o	p
NGC 3504	20.04	53.4	Sab	1.3	0.78	[31]	r	p
NGC 4424	4.37	61	Sba	1.0	0.2	[33]	o	c
NGC 7743	24.7	40	S0-a	0.4	0.1	[34]	o	p
NGC 4016	49.2	60	Sd	0.5	2.9	[31]	r	p
UGC 11748	74.4	81	Sbc	1.7	1.86	[35]	r	–
NGC 4214	7	38	I	1.5	5.18	[36]	r	–
NGC 5347	32.50	45	Sab	0.4	0.21	[37]	o	–
NGC 5850	34.2	37	Sb	1.4	1.01	[38]	o+r	p
NGC 4490	8.43	45	SBcd	0.4	1.48	[39]	r	p, i
NGC 2469	47.3	48.3	Sbc	1.1	1.0	[26]	o	–
NGC 5921	25.2	49.5	Sbc	0.9	1.65	[40]	o	–
ESO 320-024	37.17	51	Sc	1.0	0.54	[21]	o	g
NGC 3456	53.67	43	Sc	1.6	0.57	[21]	o	–
NGC 6012	25.8	46.8	SBab	1.3	0.94	[37]	o	–
IC 4722	64	45	Sc	1.0	0.80	[21]	o	–
NGC 3359	14.72	53	Sc	1.8	0.98	[41]	o	–
NGC 0864	21.41	47.6	SABc	1.9	0.90	[26]	o	–
ESO 266-015	39.64	47.8	Sbc	1.5	0.78	[21]	o	g
NGC 3810	12.17	48.3	Sc	0.6	0.40	[32]	o	–
NGC 7753	71.36	47	SABb	1.5	1.63	[42]	o	p, i

M/L_B ratio in the galaxies is about 0.3–0.5. Such low values indicate the domination of young stellar population in their radiation and also the absence of massive dark halo.

Table 2: "Heavy" galaxies with known rotation curves.

Galaxy (1)	D, Mpc (2)	$i,^0$ (3)	t (4)	M/L_B (5)	R_{max}/R_{25} (6)	Source (7)	Estimation method (8)	Note (9)
IC 5063	44.3	50.4	S0-a	14.2	0.42	[43]	o	–
IC 5096	40.7	90	Sbc	10.1	0.57	[44]	o	–
NGC 0217	53.5	90	S0a	11.4	0.62	[25]	o	–
NGC 2772	42.9	54.1	Sb	17.8	0.75	[21]	o	–
NGC 4013	11.7	90	Sb	11.2	2.4	[47]	r	–
NGC 4157	11.2	90	SABb	10.9	1.7	[48]	r	g
NGC 4772	17	67.5	Sa	12.9	1.5	[50]	r+o	–
NGC 4866	17	90	S0-a	24.9	1.8	[51]	r	–
NGC 5290	35.5	80.3	Sbc	10.7	0.58	[31]	r	p
NGC 5635	58.4	72.8	Sb	14.4	0.85	[53]	r	–
NGC 5908	46.1	65.3	Sb	10.3	0.48	[26]	o	p
UGC 03410	53.9	74.3	Sb	14.9	0.61	[55]	o	p
UGC 12591	95.1	84.6	S0-a	10.7	0.62	[25]	o	–

Abnormally low $M/L_B < 0.5$ occurs also in following objects: ESO 586-002 (S), NGC 3996(IBm), UGC 03685 (SBb), NGC 7743 (S0a), NGC 4016 (Sd), NGC5347(Sab), NGC 4490 (SBcd), and NGC 6814 (SAB(rs)bc).

The "heavy" galaxies with the highest M/L_B ratios are: IC 5063 (S0-a), NGC 2772 (Sb), NGC 4866 (S0-a), NGC 5635(Sb) and UGC 3410 (Sb). All of them have $M/L_B > 14$. However, galaxies with $M/L_B > 20$, that is at least twice higher than the ratio expected for the old stellar population, are absent in our sample. The only possible exception is NGC 4866 - an early type spiral galaxy with nearly edge-on disc. It is worth noting that a significant part of "heavy" galaxies in Table 2 has inclination $i > 80^0$, so at least some of them may fall into this category due to underestimation of their internal extinction.

If not to consider the significant systematical errors of evaluations as the cause of extreme values of M/L_B, two possible interpretations remains: either "light" and "heavy" galaxies have respectively too light and too heavy dark halo, or there exist some peculiarities of disc stellar population. Extremely low M/L_B ratio may also indicate a burst of star formation in the "light" galaxies with relatively low mass fraction of dark halo. The latter explanation is suitable for 5 galaxies, listed in Table 1 (NGC 1569, ESO 338-004, NGC 3991,NGC 1140, NGC 7714), since their blue color $((B-V)_0 \leq 0.4, (U-B)_0 \leq -0.4)$ shows that young stellar population gives significant input to their blue luminosity. However the color indices of other galaxies are considerably redder with respect to the normal color sequence of galaxies at the $(B-V)-(U-B)$ diagram.

To reduce the influence of young stars on the M/L evaluation, we also considered the luminosity of galaxies in the K-band using total 2MASS K-magnitudes, taken from HyperLeda [2]. Note that in the case of the low surface brightness galaxies a strong underestimation of luminosity in the 2MASS K-band may be as high as two stellar magnitudes [56]. By this reason NGC 4395 - a galaxy with the lowest surface brightness of our sample (effective surface brightness in the B-band according to [2] is 23.8), was excluded from our consideration.

Fig.3 shows the Tully-Fisher relation for the "heavy" and "light" galaxies, where the luminosity L_K, which characterizes a stellar population mass, is compared with maximum velocity of rotation, taken from rotation curve. The straight line represents the relation

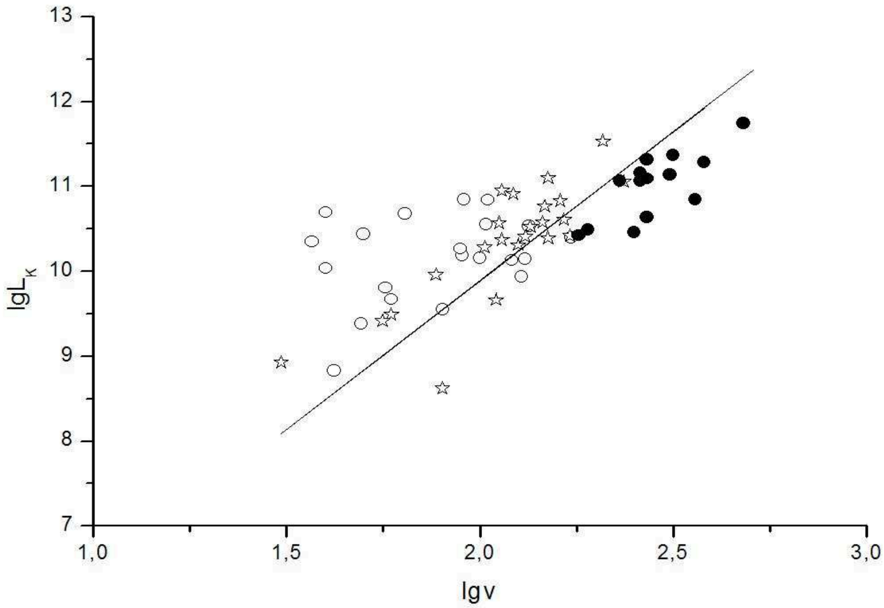

Figure 3: The Tully-Fisher relation for the “light” (open circles and asterisks show the objects with $M/L_B < 1$ and $1 \leq M/L_B \leq 2$ respectively), and for the “heavy” galaxies (filled circles).

for spiral galaxies, given by Rijke et al., [57] using the data presented by Tully and Pierce, [58]). Although the galaxies we consider were selected on the basis of M/L_B ratios, Fig. 3 demonstrates that even in the K-band our “light” and “heavy” galaxies have respectively higher or lower luminosity than it is expected from their rotation velocities, so the discrepancy may exceed an order of magnitude. This fact rules out the interpretation of “heavy” and “light” galaxies as a product of errors of light extinction correction, since the extinction effect for the K band is much lower than for the B band. Thereby, as the diagram shows, the galaxies we consider are poorly described by the Tully-Fisher relation. If their distances were determined from this relation, they would be strongly under- or overestimated.

To clarify the possible causes of abnormal M/L_B ratio, we carried out a decomposition of rotation curves, considering stellar disc M_*/L ratios in each galaxy as a free parameter. It enabled us to compare this ratios with the model ratios $M*/L$, inferred from the color of stellar population, for galaxies with reliable rotation curves and color indices found from the literature. The rotation curves were fitted by a simple model, that consists of three components: King’s bulge, thin exponential disc and pseudo-isothermal halo. The resulting estimation of the disc mass is poorly sensitive to the choice of the bulge parameters, but it depends strongly on the adopted disc radial scalelenght which is assumed to be close to the photometric radial scalelength. In the cases when the disc surface brightness distribution is poorly fitted by exponential law, we used the observed photometric profile assuming a constant mass-to-light ratio (for such galaxies there is a dash in the column ”Disc central surface density” in Tables 3, 4). A well-known ambiguity of rotation curve decomposition forced us to employ the maximum disc model. This model generally does not lead to significant overestimation of disc mass, unless slowly rotating galaxies are considered (see, for example Kranz et al., [65]).

Some examples of our rotation curve decomposition are shown in Figs. 4a, b. The

results of the modeling of the "light" and "heavy" galaxies may be found in Tables 3,4. Their columns show:
(2)– Mass of the disc within R_{25},
(3)– Total to disc mass ratio within R_{25},
(4), (5)– M_d/L_B and M_d/L_K ratios for the disc component,
(6)– $(B-V)_0$ color,
(7)– Central disc density, extrapolated to $R = 0$,
(8)– The reference sources of the disc radial scalelengths,that were used in the modeling.

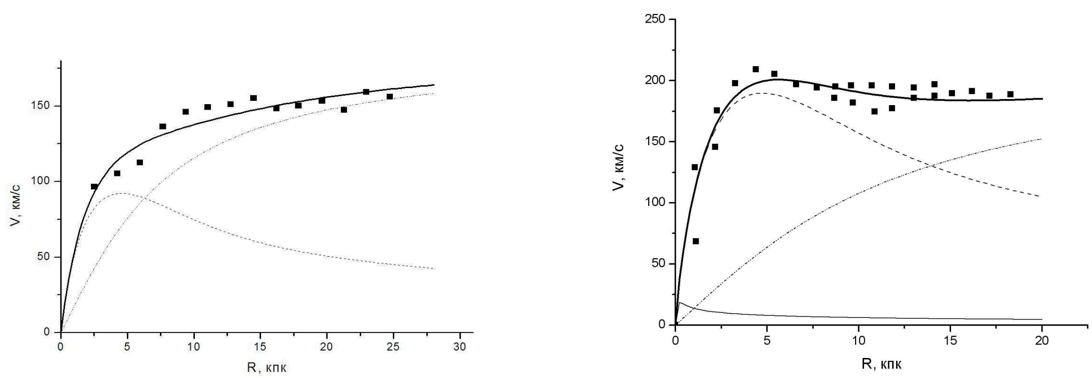

Figure 4: The examples of rotation curve decomposition. a) NGC 4826 (a "light" galaxy), b) NGC 4157 (a "heavy" galaxy).

The results of the decomposition of the rotation curves show that galaxies with different – high or low – M/L_B values may have different ratios of disc-to-total masses. For both "light" or "heavy" galaxies the disc mass fraction lays in the range $0.4 - 0.7$, although a dispersion of this ratio is higher for the "light" galaxies. At least partially, a high dispersion may be explained by their lower mean luminosity, because the maximum disc model we used can significantly overestimate the mass of some low mass galaxies.

The dynamically estimated masses of the galactic discs M_d allow us to compare the positions of the "light" and "heavy" galaxies on the baryonic Tully-Fisher relation connecting M_d with the inclination-corrected HI linewidth, which is equal to double value of rotation velocity (Fig.5). The solid line reproduces the relation, given by Gurovich et al., [66] for two samples of galaxies of normal and low luminosity for which the disc masses were estimated from their luminosity in the I band. The contribution of the gas to the disk mass was also taken into account for slowly rotating systems. With an exception of a few most slowly rotating galaxies, "light" and "heavy" galaxies we discuss follow the general sequence, in contrast with the Tully-Fisher relation $L_K - V$ where they deviate significantly from the expected relationship (Fig. 3). With some exceptions, the masses M_d of the galaxies we consider are typical for their velocities of rotation, that agrees with the conclusion made above that the cause of their low or high M/L is not an unusually low or high fraction of dark halo mass, but rather are the properties of their stellar population.

Fig. 6 shows the M_*/L_B-color diagram for the galaxies we discuss. The "heavy" and "light" galaxies are marked by filled and open symbols, respectively. Galaxies, whose disc masses were estimated by decomposition of their rotation curves (triangles) and those where only the total mass and hence the total M/L_B estimations were possible due to poor rotation curves (squares for "heavy" galaxies and circles or asterisks for "light" ones), are plotted at the same diagram. Open asterisks and circles relate to galaxies with $1 \le M/L_B \le 2$ and

Table 3: Galaxies with M/L_B <2: the results of modeling.

Galaxy (1)	$M_{tot}/M_{\odot}$ (2)	M_{disc} (3)	M_{disc}/L_B (4)	M_{disc}/L_K (5)	$(B-V)_0$ (6)	Σ_0 (7)	Photometry (8)
ESO008-001	2.79E10	0.99	0.87	1.72	-	-	[21]
ESO 038-012	7.34E10	0.36	0.37	1.58	-	-	[21]
ESO 121-006	3.26E10	0.24	0.13	3.31	0.62	-	[21]
ESO 490-028	4.19E9	0.21	0.21	1.20	-	-	[21]
ESO 565-011	4.43E10	0.44	0.81	0.47	0.73	-	[23]
ESO 586-002	2.07E10	0.95	0.32	-	-	-	[21]
NGC 2550	1.7E10	0.45	0.34	1.11	-	390	-
NGC 3396	3.76E9	1.0	0.23	0.31	-	84	-
NGC 3991	2.5E10	0.45	0.83	-	0.36	320	-
NGC 4668	4E9	0.24	0.23	0.76	0.38	95	[59]
NGC 5134	7.3E9	0.84	0.42	0.13	0.66	220	[59]
NGC 4826	4.25E10	0.25	0.43	0.55	0.71	440	[59]
NGC 5954	1.26E10	0.57	0.40	0.79	-	-	[29]
NGC 6814	1.36E10	0.62	0.18	0.17	0.67	240	[60]
UGC 03685	3.99E9	0.19	0.06	0.16	-	12	-
ESO 215-039	2.71E10	1.0	0.63	0.70	0.31	-	[21]
NGC 4618	3.39E9	0.45	0.58	1.16	0.38	250	[60]
NGC 5850	6.63E10	1.0	1.33	0.46	0.72	339	[60]
NGC 2469	2.25E10	0.45	0.28	0.79	-	600	-
NGC 5921	1.1E10	0.41	0.15	0.14	0.6	77	[60]
NGC 3359	3.69E10	0.54	0.70	1.31	0.4	360	[60]

Table 4: Galaxies with M/L_B >10: the results of modeling.

Galaxy (1)	$M_{tot}/M_{\odot}$ (2)	M_{disc}/M_{tot} (3)	M_{disc}/L_B (4)	M_{disc}/L_K (5)	$(B-V)_0$ (6)	Σ_0 (7)	Photometry (8)
IC 5063	3.5E11	0.37	3.9	0.80	0.91	1360	[61]
IC 5096	4.1E11	0.15	3.1	0.70	–	–	[62]
NGC 0217	4E11	0.23	1.9	0.34	–	1150	–
NGC 0936	1.8E11	0.69	12.5	2.02	0.9	2130	[63]
NGC 2772	1.1E11	0.60	2.5	0.62	–	980	–
NGC 4157	7.7E10	0.58	6.3	1.55	0.64	1550	[59]
NGC 4772	1.1E11	0.69	6.2	2.25	0.83	1280	[59]
NGC 5290	2.4E11	0.46	4.0	0.94	-	632	[64]
NGC 5635	6.5E11	0.49	6.0	1.71	–	1680	–
NGC 5908	4.2E11	0.40	4.3	0.94	0.81	1670	–
UGC 03410	2.1E11	0.56	6.9	1.12	–	995	–
UGC 12591	1.1E12	0.45	4.8	0.90	–	5700	–

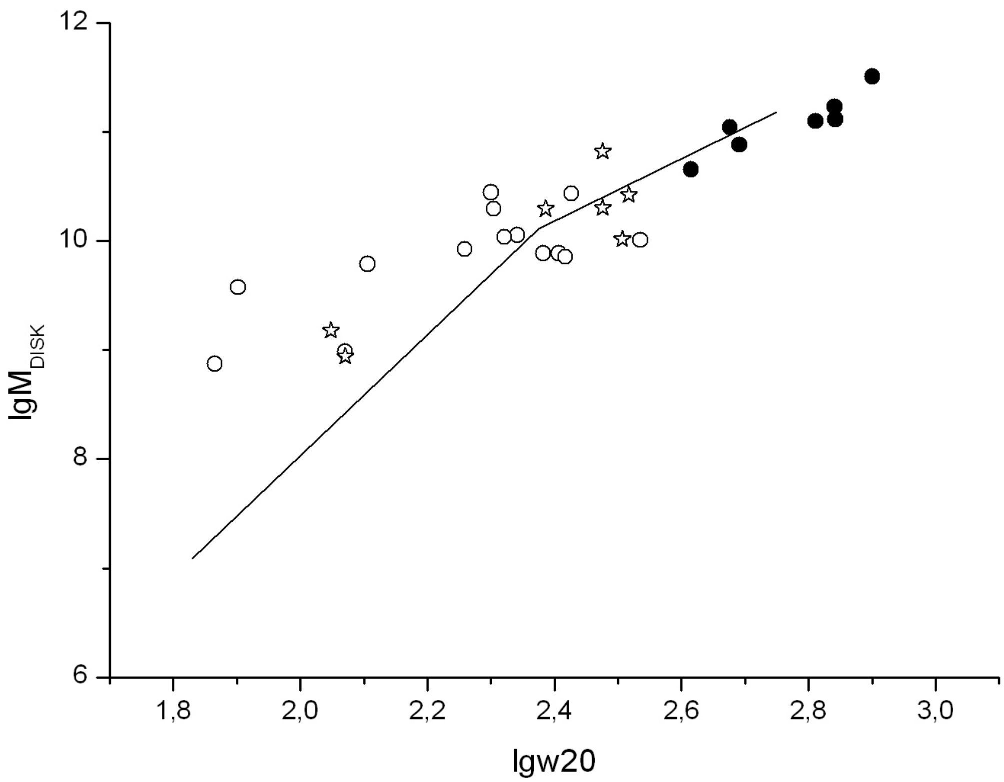

Figure 5: The baryonic Tully-Fisher relation $lgM_* - lgW_{20}$ for "light" (open symbols) and "heavy" (filled symbols) galaxies; circles and asterisks show galaxies with $M/L_B < 1$ and with $1 \leq M/L_B \leq 2$ respectively. The solid line reproduces the relation given by Gurovich et al., [66].

with $M/L_B < 1$ respectively. As far as the total M/L_B ratio is the upper limit of disc M_d/L_B ratio, the corresponding symbols are marked by the arrows. The vertical lines connect the values of M/L_B and M_d/L_B for the same object. Here we ignore the difference between the disc mass M_d and mass of the stellar population M_*. The straight line represents the model relation "color - M_*/L", for evolution models of stellar population with the scaled-down (light) Salpeter IMF (Bell, de Jong, [3]). The other shapes of stellar IMFs, suggested by different authors, shift the model sequence vertically in such a way that the values of $\log(M_*/L_B)$ changes only within a few tenths of dex (see, for example Portinari et al., [4]).

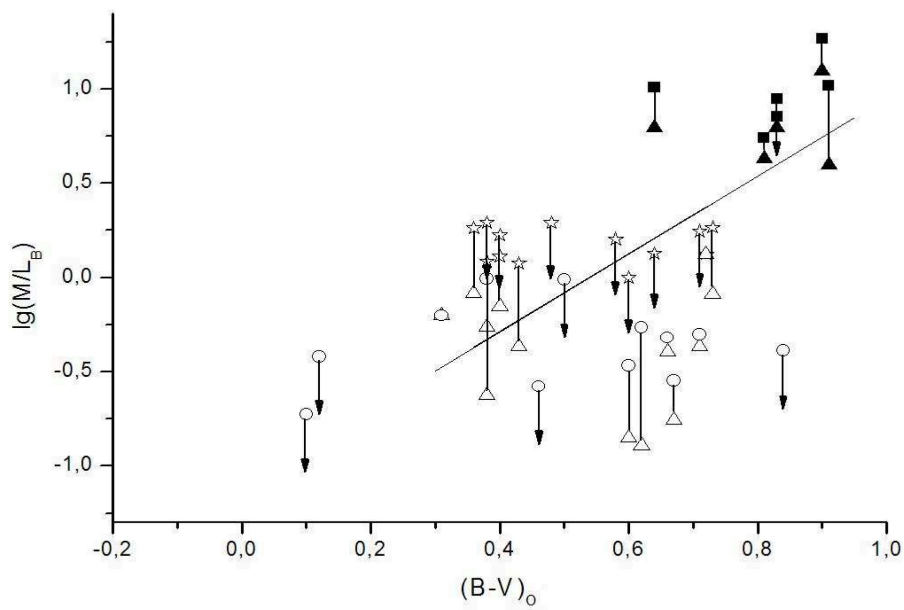

Figure 6: The M_*/L_B-color diagram for the "light" (open symbols) and "heavy" (filled symbols) galaxies. The upper symbols (squares, circles and asterisks) show the total M/L_B ratios (circles and asterisks correspond to the galaxies with $M/L_B < 1$ and $1 \leq M/L_B \leq 2$ respectively). The triangles mark the disc M_*/L_B ratios. The vertical lines connect the symbols, corresponding to the M/L_B and M_*/L_B in the same object. The solid line represents the model relation for stellar systems [3].

Fig. 6 shows that the stellar disc M_*/L_B ratios poorly follow the expected model sequence. However the situation is different for the "light" and "heavy" galaxies. The M_*/L values for the "heavy" galaxies lay systematically above the model relation, but generally not far from it, especially if to remember that we used the maximal disc solution. A small number of "heavy" galaxies considered here does not allow to make a confident conclusion about any systematic peculiarities of their properties. Two cases, however, deserve a special attention. This first one is $IC5096$, the galaxy with the highest M/L_B. Its position on the diagram allows to conclude that there is a significant predominance of the dark halo mass over disc mass in this galaxy. The seconds case (NGC 936, the leftmost of the filled symbols) suggests a stellar disc, not halo, that is unusually massive for the observed luminosity and color, indicating the possibility of exotic stellar mass function.

The situation with the "light" galaxies is more interesting. Two galaxies with the lowest values of $(B-V)_0$ experience a burst of star formation (NGC 1569 and $ESO338-004$), which explains their low total M/L_B ratios. The color indices of these galaxies cannot be described

by the simple model [3] of stellar systems with monotonous evolution of star formation. Most of the other "light" galaxies lay below the expected model relation, especially if to take into account that the maximum disc model we used may overestimate M_*/L ratio. It corresponds to the following galaxies: NGC 4214, 5134, 5347, 5921, 6814, 7743 and ESO $121-006$. These objects require individual and more detailed investigation. Their low M/L_B and M_*/L_B ratios cannot be explained by the excess of OB-stars, since their color $(B-V)_0 > 0$, except NGC 4214. This conclusion remains to be the same with M_*/L_K instead of M_*/L_B at the diagram.

Discs of the "light" galaxies listed above are distinguished not only by their low mass-to-light ratio, but also by the low surface density. Their central surface densities obtained from the rotation curve decomposition lay in the range from 100 (or even less) to a few hundred $M_\odot/pc^2$ (see Table 3). For reference: the typical central surface brightness of the discs of HSB spiral galaxies is $\mu_{0B} = 21 - 22^m/sq.arcsec$, hence, for the typical ratio $M_*/L_B = 4$ it corresponds to the central surface density of $400 - 1000$ $M_\odot/pc^2$. Non-typical low density of a disc may indicate a strong deficit of stars with masses less than a few solar masses. Their absence affects strongly the total mass rather than the total luminosity of a disc. Since the masses of stellar discs are provided mostly by the old stellar population, the expected bottom-light initial mass function in the "light" galaxies may be associated with the early epoch of disc formation, and not necessary with the present time star formation.

To summarize, there is no sole explanation for the extremely low and extremely high values of total M/L_B ratios in the galaxies we consider in this paper. In some cases they are clearly associated with errors of velocity or luminosity estimations, but in other cases we encounter with the real features of galaxies, such as non-typical disc-to-halo mass ratios, or, especially for the "light" galaxies, with stellar population peculiarities such as burst of star formation or non-typical stellar initial mass function.

4 Conclusions

1. From the $M/L_B - (B-V)_0$ diagram, plotted for about 1300 discy galaxies, it follows that the M/L_B ratio of galaxies increases with the color index, although not so steep as it is predicted by the stellar population evolution models. This allows to conclude that the ratio between the dark halo and stellar disc masses decreases along the color sequence towards the "red" galaxies with old stellar population. However, some galaxies do not follow this general trend, and this cannot be explained in all cases by the errors in their rotation velocity or luminosity estimations. Virgo cluster galaxies do not outlay by their positions on the diagram from the others.

2. Extremely high M/L_B ratios $M/L_B > 10$ are rare and usually occur in the "red" galaxies. With few exceptions (for example - IC 5096) they possess not too massive dark halos, being normal galaxies with old stellar population. Nevertheless, there also exist some " heavy" galaxies with a mixture of old and young stars, so their high M/L_B ratio can be associated with a very massive dark halo.

3. Low ratios $M/L_B < 1$ of galaxies are also not caused by a sole reason. In some cases they reveal the actively ongoing star formation, but this interpretation is definitely not valid for some galaxies: they have an extremely low both total M/L_B and disc M_d/L_B ratios. These ratios are too low to be in agreement with the observed color of galaxies even in the absence of the halos, indicating the abnormal initial stellar mass function with a strong deficit of low massive stars.

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